# A Goal-oriented Methodology for Treatment of Patients with Multimorbidity - Goal Comorbidities (GoCom) Proof-of-concept Demonstration

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**Abstract.** Advancement in medicine has increased the average population age, however, physicians are still burdened with the complexity of treatment of multimorbidity patients due to many potential interactions among the patient's medications, and diseases. We developed a goal-oriented methodology for management of multimorbidity patients called GoCom (for Goal Comorbidities). GoCom's aim is to help manage the patient's changing health state that may prompt new goals to arise. GoCom utilizes computer-interpretable clinical guidelines formalized using the PROforma representation. The guidelines are modeled according to a previously published guide on modeling goal-oriented, metaproperty enriched tasks in PROforma. The tasks are retrieved by the main algorithm of the system named the "Controller" that creates a hierarchical goal-oriented tree structure that is personalized for the patient according to their specific data. Tree structures are created for all of the patient's problems and are formed as a patient forest. The Controller behavioral patterns reason over the patient data and create clinically-valid solutions that are presented to the physician with generated explanations. We evaluated GoCom for correctness and completeness with complex multimorbidity case studies. The first evaluation was a pilot study with ten 6th year medical students and the second evaluation was with 27 6th year medical students and interns. Use of GoCom increased completeness and correctness and the explanations and visualization were viewed as useful by the participants.

**Keywords:** Multimorbidity, Comorbidity, Decision-support, Computer-interpretable guidelines

## 1 Introduction

Multimorbidity has become more common with the increase of the average age of patients. Physicians have many skills and tools to rely on, but the complexity of treatment for multimorbidity patients remains a burden. Physicians may use Clinical Practice

Guidelines (CPGs) and Computer Interpretable Guidelines (CIGs) to support their decision making [1], however CPGs and CIGs focus largely on single morbidities that do not account for interactions among the patient's diseases and medications that may occur when recommending treatments from multiple guidelines [2]. Goals are especially important for clinical decision support as they aid in analyzing the patient's treatment regimen [3], detecting problems [4] and suggesting solutions [5].

In this research we developed a goal-oriented methodology for treatment of multimorbidity patients called GoCom (for Goal Comorbidities) [6]. The methodology presents the process of creating and adjusting the patient's treatment regimen as a combination of goals acquired by the patient as their health state changes. This approach helps detect and mitigate inconsistent recommendations that can result in adverse events. Additionally, explanations are generated for each proposed non-conflicting management plan and the goals that are addressed in that plan. The methodology is designed using existing health standards (HL7 FHIR [7]), terminologies and vocabularies (NDF-RT[8], SNOMED[9], MedDRA[10]), which are combined with the goal-oriented modeling of guidelines represented using the PROforma formalism [11] that are enriched with metaproperties in order to represent clinical goals such as diagnosis goals, treatment or prevention goals, action-enactment goals and state achievement goals (e.g., for expressing physiological effects such as decreased platelet aggregation) [12]. This representation facilitates the creation of a flexible range of solutions, with different levels of abstraction of reasoning.

## 2 Methods

GoCom's architecture is based on the Model-View-Controller pattern [13]. The "Model" is used to store the CIG knowledge base and patient specific data in a Fhirbase database. The "View" is implemented as the interface (Figure 2) and the "Controller" is extended to contain the main algorithm of the system. The Controller utilizes the PROforma CIGs and standards to create a patient-specific goal-forest structure that contains a hierarchical goal-tree for each of the patient's problems. The Controller then searches the goal-forest for inconsistencies [14], while considering the different levels of abstraction of medications and groups of medications in the NDF-RT (e.g., Omeprazole is-a Proton Pump Inhibitor).

### 2.1 Mitigation

An example case study that one may consider for explaining GoCom's mitigation process, involves a 78-y-old female patient. The patient is taking Aspirin for secondary prevention of cardiovascular disease and Omeprazole for her duodenal ulcer that she was diagnosed with after she started taking the Aspirin. Currently, the patient is diagnosed with osteoporosis. Since Proton-pump Inhibitors are a risk-contributing factor in osteoporosis, the guideline recommends to stop them. Thus an inconsistency occurs between the duodenal ulcer guideline that recommends Omeprazole and the osteoporosis guideline that recommends to stop Proton-pump Inhibitors – a medication group that subsumes Omeprazole.

When the Controller finds an inconsistency between a pair of goals (e.g., Start Omeprazole – goal_1, stop Proton Pump Inhibitor-goal_2), a duplicate alternative patient-forest is created for each goal in the inconsistency and mitigation is attempted. The Controller activates the guideline that recommended the goal and searches for an alternative sibling that could be recommended by the guideline instead of the active goal. If such a sibling is not found, the Controller removes the inconsistent goal (goal_1) from the alternative forest and proceeds to apply the same reasoning to the other side of the inconsistency (goal_2). This creates a total of two alternative patient forests for each inconsistency. Additional patient forests may be created if one of the inconsistent goals (goal_1 or goal_2) has a dependency that associates it with another goal (e.g., Omeprazole was prescribed to counteract the effects of Aspirin). The dependency is indicated as part of the goal metaproperties in the CIG (Figure 1). When the Controller identifies such a dependency, it is mitigated in the same way as an inconsistency. The Controller tries to find a replacement sibling for the goal that has the dependency (e.g., start Omeprazole to counteract Aspirin) as well as for the dependent goal (e.g., start Aspirin) and removes the goal in the respective alternative forest. Finally, each alternative forest is checked for inconsistencies and inconsistent or duplicate alternative forests are removed from the solution range. We refer to a non-conflicting alternative forest as an "Option-set". The controller generates an explanation for each Option-set as well as for each recommended goal in the Option-set, based on the goal's life cycle status (e.g., accept, reject, cancel, complete) and the Option-sets with explanations are displayed to the user. Additional descriptions of the algorithm and patterns can be found in Kogan et al. [15].

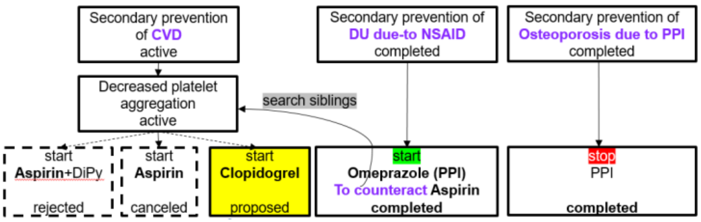


**Fig. 1.** The third option-set that is created when the Controller identifies the dependency "start Omeprazole to counteract Aspirin".

## 2.2 Presentation

The interface (Figure 2) displays to the physician-user information and functionalities that aid the decision-making process: (a) Patient demographic details, (b) Patient visits, (c) Patient investigations (including extended tables and images), (d) Patient problems and their associated goals and treatments, (e) The Controller window where the system suggests solutions to inconsistencies and also displays non-conflicted goals.

The user can search for a patient, as well as create a new patient and add a new diagnosis or a visit to the patient record.

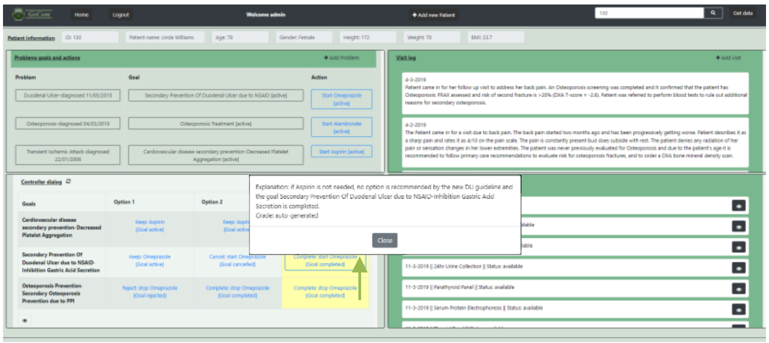

**Fig. 2.** A screenshot showing an example of the user interface produced by GoCom for a patient with three morbidities. The insert shows an explanation for the goal Inhibition Gastric Acid Secretion for one of the option sets (Option 3).

## 3 Results

GoCom was evaluated for functionality and usefulness with six complex multimorbidity case studies. The first evaluation was a pilot study with ten 6$^{th}$ year medical students and two cases. The second evaluation had 27 6$^{th}$ year medical students and interns and 6 cases. GoCom was shown to increase completeness significantly: 0.44 without the system, 0.71 with the system (P-value of 0.0005) in the first evaluation, and in the second evaluation: 0.31 without the system, 0.78 with the system (P-value $< 0.0001$). In the first evaluation correctness was high and did not increase significantly: 0.91 without the system, 0.98 with the system (P-value $\geq 0.17$). In the second evaluation the correctness did increase significantly: 0.68 without the system, 0.83 with the system, (P-value of 0.001).

## 4 Conclusion

GoCom is a goal-based methodology that combines hierarchical goal modeling, standard ontologies and terminologies and evidence-based recommendations in order to produce aggregated Option-sets with explanations that would provide a flexible range of solutions that can help guide the patient to a better treatment plan. While GoCom was implemented only as a proof-of-concept that is meant to take the first steps in tackling the challenges that goal-oriented multimorbidity decision support presents,

It seems feasible that GoCom can help clinicians to be more complete and correct in diagnosis and management. Our planned future work includes detection of adverse events, temporal reasoning, addressing goal prioritization and patient preferences.

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